Sampling

Sky

Deploying global observatories to improve climate models

In March, the Intergovernmental Panel on Climate Change (IPCC) released its fifth assessment, citing hundreds of studies about increased carbon dioxide in the atmosphere and the planet's ominous fever. Given the complexity of the climate, and the multitude of influences upon it, a vast amount of data was required to inform the authors about what is going on in the global ecosystem.

The Sun warms the earth, but our habitable climate is actually determined by a subtle balance between how much solar radiation is absorbed, rather than reflected, and how much the earth itself radiates back to space at infrared frequencies. Some of this infrared radiation gets trapped by atmospheric greenhouse gases (GHGs), such as carbon dioxide (CO_2) and water vapor. Although GHGs are a major source of warming, clouds and aerosols—tiny particles in the air and clouds—significantly affect this radiative balance as well because they too can either absorb or reflect the radiation. However, the complexity of this relationship is far from completely understood. According to the IPCC report, "clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the earth's changing energy budget."

One of the reasons for this uncertainty is that not all clouds are the same. Their effect on the climate varies with altitude, topography, and weather conditions. And their aerosol ingredients don't always have the same effect: some make a cloud more reflective and others make it prone to absorbing heat. Furthermore, some high clouds can act as a blanket, trapping heat and reflecting it back to the earth's surface, while low clouds can reflect the sunlight away, producing a cooling effect. As every skier knows, it can often be warmer under the cloud cover of a snowstorm than on a cloudless February day. Conversely, in the middle of a hot July afternoon, a few clouds blocking the sun might be the only relief from the heat.

So, do all these local variations—a little warming over here, a little cooling over there—really impact the global climate? Yes, because they alter how much radiative energy is kept in the atmosphere, and those changes add up. However, to understand the cumulative effect, scientists need more data. In order to incorporate into a climate model both the worldwide variation in topographical environments and meteorology, coupled with the changing chemistry of the atmosphere at differing altitudes, it is necessary to collect data on various scales from a wide range of locations.

To address these challenges, the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility has been operating climate observatories worldwide, and supporting climate scientists, for over two decades. Their mission is to enable high-quality data collection in new or under-sampled sites where the atmosphere can be studied at multiple scales. By including data from diverse environments, the reliability and predictive power of climate models can be improved. For instance, instead of predicting that the temperature could increase from anywhere between 1°C and 4°C, the models might indicate a narrower range of only 2–3°C.

At the heart of this major enterprise is a team called FIDO (Field Instrument Deployments and Operations), consisting of 14 Los Alamos project managers and operations specialists. The FIDO team is one of the DOE's go-to groups for coordinating every aspect of the international ARM campaigns. They make the measurements possible by deploying mobile laboratories and state-of-the-art equipment to the far corners of the earth to gather data that improves scientists' understanding of atmospheric phenomena.

"ARM has changed the paradigm. It enables anyone, anywhere to study and model the climate," says Mark Miller, a Rutgers University professor and lead scientist for two ARM measurements sites. "It is widely considered to be one of the best climate programs the government has."

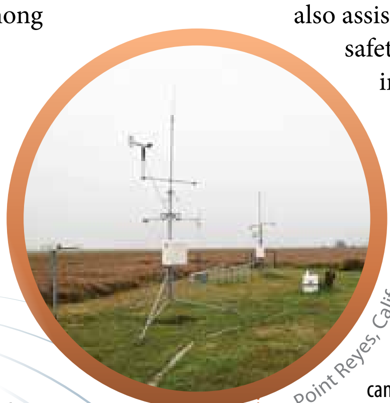
Global observatories

Established in 1989, today's ARM Facility operates four fixed research sites, three mobile laboratories, and a research aircraft to study a range of climate conditions. The DOE solicits proposals from the international scientific community to determine the locations for the mobile facilities, and the data, once collected, are entered into a large database freely available to anyone in the world.

"The goal is not to measure climate change, but instead to measure the microphysical properties of the atmosphere to improve climate modeling," says Kim Nitschke, the Los Alamos FIDO Facility Operations Manager. Los Alamos has been part of the ARM Facility since it was founded, when the DOE distributed the management of the facilities among its national laboratories. Los Alamos was initially given the responsibility for three locations in the Tropical Western Pacific: Manus Island in Papua New Guinea, the Republic of Nauru, and Darwin, Australia.

When the program expanded into an official DOE scientific user facility in 2003, ARM created mobile facilities that could be taken to various locations around the world to gather data for periods of 6–24 months. Los Alamos currently operates the first ARM mobile facility (AMF1) and is preparing to take on the second, AMF2. These mobile facilities are rebuilt at each new location using modified shipping containers and a baseline suite of instruments, data communications, and data systems—plus room for additional non-ARM instrumentation. Types of measurements that might be obtained at a mobile facility include measuring the vertical velocity inside thermals (columns of rising air) and clouds; the chemical composition of individual particles in the atmosphere; the life cycle and microphysics of clouds; and a profile of surface radiation, precipitation, or wind speed.

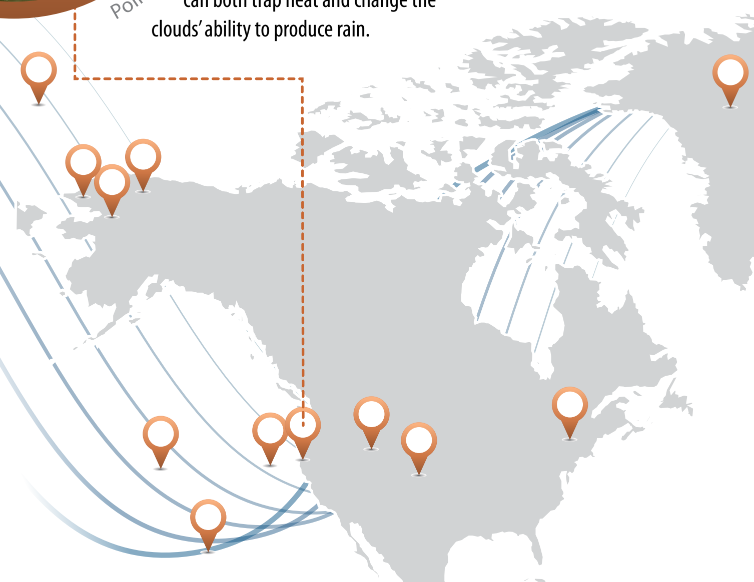
The FIDO team's work begins before a mobile site location is even chosen. During the DOE proposal selection process, FIDO evaluates and determines each potential project's feasibility. This includes budget estimation and risk analysis for safety and security. Once a site is chosen, FIDO conducts pre-deployment visits to identify regulations, the availability of local resources, and possible cultural or language barriers. Multiple shipping containers carry the scientific instrumentation, and the team is then responsible for commissioning the physical facility (which might include building infrastructure) as well as the set up, calibration, and maintenance of the instruments. FIDO coordinates with the collaborating scientists to transport their equipment, but also assists with their travel, health, and safety, as they may visit the sites for intensive operational periods.



Point Reyes, California, was the site of the first ARM mobile facility deployment in 2005 for a study of marine stratus clouds, which exert a large-scale cooling effect on the ocean surface, sometimes producing drizzle. These clouds, however, are susceptible to the effects of anthropogenic aerosols that can both trap heat and change the clouds' ability to produce rain.

Sum of the Skies

On any given day, a bank account may experience a handful of transactions—some deducting money and others contributing, some large amounts and others small. But all that really matters at the end of the month or year is the net amount. This is similar to the global energy balance. Cloud cover and aerosols over some areas of the planet may trap heat, adding warmth to the atmosphere; in other areas, the clouds may reflect solar radiation away, cooling the earth below. What really matters is the net effect—whether the overall global atmosphere is warmer or cooler. However, when it comes to modeling the future climate, scientists have discovered they need a better understanding of all the local transactions. Atmospheric additions of greenhouse gases and anthropogenic aerosols add up quickly, but when combined with local weather and topography, they don't always result in a predictably consistent outcome. The more data scientists can gather on the types of changes that occur and why, the more accurately they may be able to predict the future balance.



The continuous collection of high-quality data requires daily on-site effort, for which FIDO hires and trains local personnel at each site, and Los Alamos members travel back and forth frequently to manage each deployment.

A major responsibility of the FIDO team is the diplomatic coordination of international agreements between the United States, participating institutions, and foreign governments to allow both the import of scientific equipment (including aircraft) and the export of data—which are deemed by some to belong to the country of origin. Sometimes these negotiations can be tricky. For example, pollution is a byproduct of development, which is considered essential in some countries, so there are economic and political implications to collecting evidence that may suggest pollution is associated with climate change. FIDO also has to navigate local bureaucracies. For instance, in Niger, the best way to import the ARM equipment was to lease a Boeing 747 jet, but that first required visiting multiple Nigerian agencies to determine who was in charge of the airport where it needed to land.

All packed, where should we go?

The sites chosen by the DOE and the scientific community for ARM facilities are often in remote, undersampled areas that may exhibit particularly interesting atmospheric phenomena.

"We don't really understand enough about the natural state," says Manvendra Dubey, a climate scientist at Los Alamos who works with the FIDO team. "So ARM sites try to go after interesting, missing pieces."

The problem is that when it comes to studying the natural state, it can be difficult to find places on Earth that are untouched by humankind. Scientists have evaluated the fossil record, tree rings, ice cores, etc., to understand the history of the climate in search of comparative data to help answer, "What happens to the climate when people live here?" But the fact remains that, for as long as scientists have been documenting the climate, there have been people living on Earth. Most of the natural-world data are entangled with multiple variables introduced by humanity—far from the controlled experimental conditions students learn in science classes.

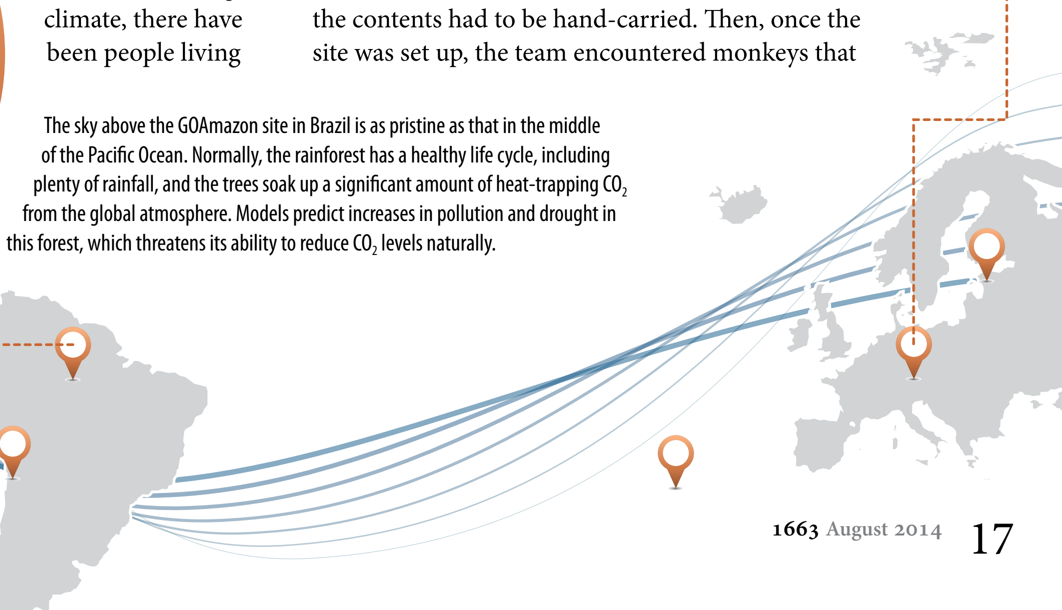
One of those entanglements involves tiny aerosols, which are about a tenth of a micron, or one ten-thousandth of a millimeter, in size. Depending on their type, aerosols can reflect or absorb sunlight. But they can also act as cloud condensation nuclei (CCN), which means that water vapor molecules can gather around an aerosol particle to form a droplet, which then joins with millions of other droplets to create a cloud.

In nature, salt particles in the ocean air and organic molecules from lightning-ignited wildfires are two of many known aerosols that can serve as CCN to aid in cloud development. But pollution from anthropogenic activities, such as soot from smokestacks or burning biomass, also adds aerosols to the atmosphere. The types of aerosols present can determine which kinds of clouds are formed, if the clouds are reflective or absorptive, and whether or not the clouds produce rain.

Some of the ARM mobile facilities have been located at or near major metropolitan areas to study the effects of these anthropogenic aerosols. In 2011, a mobile facility was erected in the Ganges Valley—a densely populated area in Northern India flanked by the Himalayan Mountains, with cement factories, steel mills, and coal-fired power plants all contributing to the aerosol load. The location itself presented quite a challenge for the FIDO team, having to transport the shipping containers up narrow switchbacks with steep cliffs to reach the mountaintop site. In fact, some of their deliveries couldn't be driven to their final destination, and the contents had to be hand-carried. Then, once the site was set up, the team encountered monkeys that

Mountainous areas with complex terrain can force moist air to rise quickly, forming thick rain clouds that produce heavy rainfall called orographic precipitation. In 2007, the ARM mobile facility AMF1 deployed to the Black Forest in Germany to study orographic precipitation because it is markedly different from other rain and is difficult to predict, which can result in unexpected storms and flooding.

The sky above the GOAmazon site in Brazil is as pristine as that in the middle of the Pacific Ocean. Normally, the rainforest has a healthy life cycle, including plenty of rainfall, and the trees soak up a significant amount of heat-trapping CO_2 from the global atmosphere. Models predict increases in pollution and drought in this forest, which threatens its ability to reduce CO_2 levels naturally.



Local staff members launch a weather balloon during the ARM mobile facility deployment in Niamey, Niger, in 2006. Here, international scientists studied the effects of Saharan dust—which can block up to 85 percent of solar radiation—on the monsoon system that brings critical rainfall to the region. Although this dust can have a cooling effect, the heat is needed to drive the monsoon.

would chew through equipment cables and steal food. There was also the occasional panther alert. The science, however, was a success; scientists used the facility to study how the pollution in the valley affects the monsoon rains in the area. Some prior studies suggested the pollution could intensify the monsoon, while others suggested the opposite. The truth turns out to be a little bit of both.

Life-sustaining rain happens to require a very particular set of circumstances. When a cloud droplet grows to 20 microns in diameter, it falls through the cloud, gathering more droplets, and increasing in size to a few millimeters. But if no droplet reaches 20 microns, the cloud just keeps growing without producing rain. To increase the likelihood of rain, it is important for clouds to have a heterogeneous population of aerosols, as different aerosols come in different sizes. Pollution, however, tends to create many smaller aerosols—which can result in bright, crisp looking clouds that do not produce rain. On the other hand, a strong current of warm air rising from the ground into the cloud can literally force a cloud to rain.

At another ARM site in the Azores Islands off the coast of Portugal, data are being gathered on drizzly boundary-layer clouds—those found between the earth's surface and an altitude of about 1–2 kilometers—that passively filter sunlight and influence and modulate sea surface temperatures. Studying their detailed vertical structure is valuable as these boundary environments are ubiquitous to global coastlines. Although this lower marine atmosphere tends to be stable, and tends to prevent air masses from mixing vertically, scientists have discovered that when plumes of polluted air from North America and Europe settle above the boundary-layer clouds, they do mix downward, contributing more anthropogenic CCN to the clouds.

"This is where ARM comes in," explains Miller. "Satellite data cannot give a detailed understanding of what is happening in these clouds. It is important to look at a diversity of different columns in the atmosphere."

It's not just about the rain, either. Climate models frequently underestimate the occurrence and persistence of marine boundary-layer clouds, which is a problem because they are so common. Without considering them, the models misrepresent how much sunlight is reflected away by these clouds versus that absorbed by the ocean. This discrepancy is as dramatic as the comparison of light reflected by a snow-covered surface to that absorbed by a dark parking lot. In other words, if the boundary-layer clouds are present and reflective, a lot of sunlight is not hitting the sea. Data from the Azores facility will help quantify how these boundary-layer clouds impact the radiative budget of the planet.

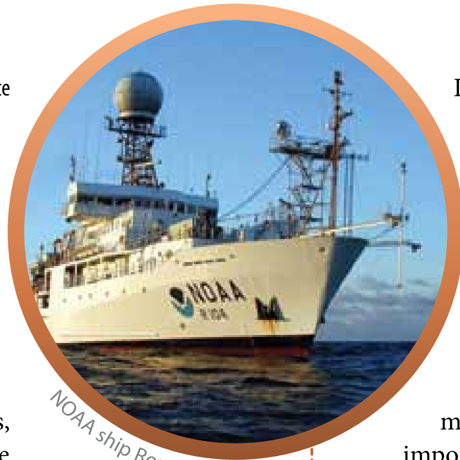
Navigating the green ocean

Deep in the Amazon rainforest in Brazil is a place called Manacapuru, where the green broadleaf forest stretches beyond the horizon. Often referred to as the green ocean, this area's atmosphere is pristine—as free from human influences as that in the middle of the Pacific Ocean—with daily rainfall to ensure that any contaminants that do arrive in the air are regularly washed away. Earlier this year, the FIDO team deployed AMF1 to Manacapuru to set up what may be the closest they've yet come to a perfectly controlled experiment. By studying the environment in the Amazon, and the cloud and precipitation cycle above the forest, the scientists hope to learn much more about the natural processes in place. But the site has another advantage as well. Only about 45 miles to the east is the city of Manaus, with a population of 2.5 million, which uses

These clouds over the Ganges Valley in India include thousands of small, pollution-derived cloud condensation nuclei per cubic centimeter, some of which reflect sunlight (and therefore produce a cooling effect) but may also, as a whole, suppress rainfall.

Clouds in clean air, such as these over the islands of the Maldives, tend to have large droplets formed from hundreds of large cloud condensation nuclei per cubic centimeter, making them suitable for creating rain. The AMF2 field-research facility took measurements in the Maldives in 2009.

FIDO and the ARM Facility sometimes participate in field campaigns that deploy instrumentation on ships to gather atmospheric data from the middle of the ocean where there are few (if any) anthropogenic aerosols.

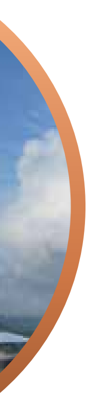


NOAA ship Ron H. Brown

high-sulfur oil as its primary source of electricity. So, when the wind changes direction and a plume of sulfuric-acid-polluted air arrives from Manaus, scientists can directly observe the changes.

To set up the Green Ocean Amazon site, GOAmazon for short, FIDO shipped 16 containers to Brazil and coordinated the set up and operation of instruments for more than 100 collaborating scientists from 24 participating institutions. The site will operate for two years, including an intensive operational period in the rainy season and another in the dry, fire season. (Some fires are natural in the life cycle of the forest, but many are deliberately set as part of deforestation for agriculture and development.)

The Amazon environment will be especially valuable for studying the anthropogenic versus natural aerosols and the atmospheric chemistry that changes them. In addition to salt and sulphuric acid acting as CCN, another family of molecules called isoprenes—some of which are produced by trees as an insect repellant but are widely recognized for their pine scent—are also emitted into the atmosphere and contribute to cloud formation. Isoprenes on their own are not CCN but can interact with other molecules in the atmosphere to create them.



One of the problems scientists have when they study various types of aerosols in a cloud is that the numbers don't always add up: the total number of CCN measured in the environment is more than the number of anthropogenic CCN plus natural CCN. Evidently, some other chemistry is happening, which they refer to as gas-to-particle conversion, to enhance the number of cloud droplets. The question is, can they measure and predict how much enhancement takes place when anthropogenic aerosols are present?

In addition to evaluating the unique blend of aerosols in the atmosphere of Manacapuru, the scientists participating in GOAmazon will also be evaluating other factors that influence climate, such as rainfall, temperature, and CO_2 content. For instance, Dubey's Los Alamos Atmospheric Observations Science team has included, as a guest instrument, a new Solar Fourier Transform Spectrometer to measure concentrations of greenhouse gases such as CO_2 and water vapor over the rainforest at regional scales to understand how the forest responds to climate change, which many climate models suggest will bring more droughts. Since the Amazon rainforests currently soak up large amounts of CO_2 (partially mitigating the increases from human activity), it is important to understand how these forests will respond to changes in water availability. If the droughts kill off parts of the forest, then the atmospheric CO_2 will increase more rapidly, creating a damaging feedback loop.

Dubey's system was previously set up in the Four Corners area in New Mexico, to monitor CO_2 and pollution emissions from two large coal-fired powerplants in the region. Although it was not part of the ARM Facility (instead a Los Alamos internal project), the FIDO team assisted with the deployment.

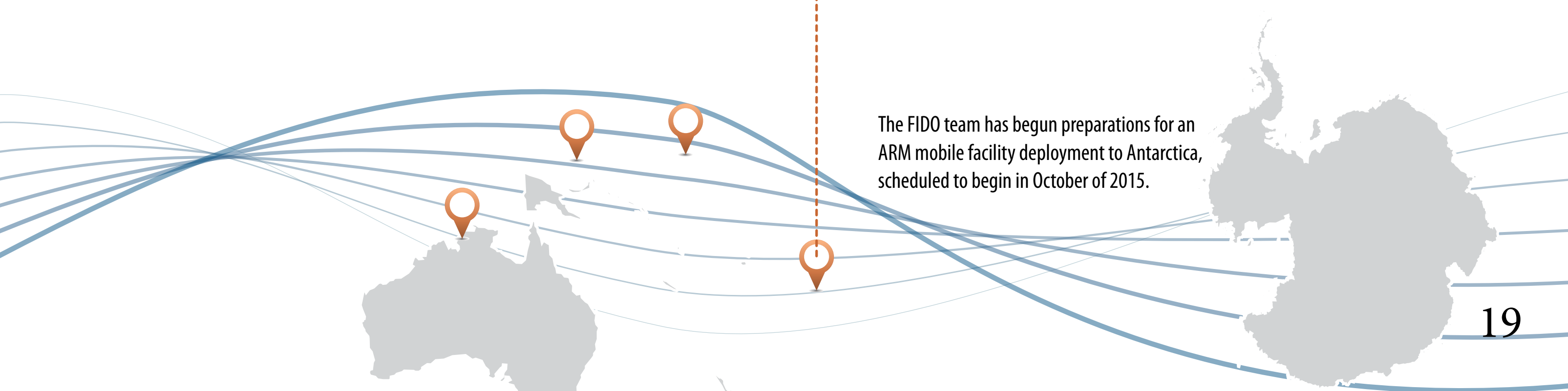
"I can't do this work without them," says Dubey. He explains that the support infrastructure is vital to enable scientists to take their instruments to remote places for conducting their research.

Predicting the planet's fate

Thousands of scientists worldwide are trying to predict the future of Earth's climate—trying to accurately understand the consequences of the human interaction with the planet. Clouds and aerosols may be only one part of the climate-change puzzle, but they are a significant one. In the IPCC report, discussions on clouds and aerosols cited data from ARM facilities more than 140 times.

Advanced computer models have proven to be valuable for predicting what the future climate may be like, but the answers they put out are only as good as the data that are put in. More real-world examples of the interplay among radiation, clouds, and aerosols hold the key to improving their predictions. And by providing an opportunity for researchers to take their labs to the ideal locations for their science—no matter what obstacles may exist—and then providing the data to any person who might need it, the FIDO team and ARM Facility are playing a vital role in climate research.

-Rebecca McDonald



The FIDO team has begun preparations for an ARM mobile facility deployment to Antarctica, scheduled to begin in October of 2015.